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(54) Process for the production of synthesis gas.

(57) Process for the production of synthesis gas with an increased H<sub>2</sub>/CO-ratio from normally gaseous hydrocarbons comprising the following steps:

- a) at least one normally gaseous hydrocarbon is converted into a synthesis gas comprising H<sub>2</sub> and CO by partial oxidation with an oxygen-containing gas;
- b) at least one normally gaseous hydrocarbon is converted with steam into a gaseous mixture comprising H<sub>2</sub> and CO;
- c) the gaseous mixture comprising H<sub>2</sub> and CO, formed in step (b) is separated into a CO-containing stream and a H<sub>2</sub> stream;
- d) the H<sub>2</sub>/CO-ratio of the synthesis gas produced in step (a) is increased by adding at least part of the H<sub>2</sub> stream obtained in step (c) thereto.

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PROCESS FOR THE PRODUCTION OF SYNTHESIS GAS

The invention relates to a process for the production of synthesis gas with an increased H<sub>2</sub>/CO-ratio from normally gaseous hydrocarbons comprising the following steps:

- a) at least one normally gaseous hydrocarbon is converted  
5 into a synthesis gas comprising H<sub>2</sub> and CO by partial oxidation with an oxygen-containing gas;
- b) at least one normally gaseous hydrocarbon is converted with steam into a gaseous mixture comprising H<sub>2</sub> and CO;
- c) the gaseous mixture comprising H<sub>2</sub> and CO, formed in step  
10 (b) is separated into a CO-containing stream and a H<sub>2</sub> stream;
- d) the H<sub>2</sub>/CO-ratio of the synthesis gas produced in step (a)  
is increased by adding at least part of the H<sub>2</sub> stream obtained in step (c) thereto.

15 An object of the invention is to increase the H<sub>2</sub>/CO-ratio of a synthesis gas resulting from the conversion of normally gaseous hydrocarbons thereby enabling the reaction of the carbon compounds with an optimal or near optimal consumption of energy and materials in the manufacture of synthesis gas  
20 from gaseous fuels. By-products and waste products from chemical synthesis and natural gas can be employed as the gaseous fuels.

In the autothermic partial oxidation of hydrocarbons the necessary thermal energy is supplied by the process itself via  
25 partial combustion of the feedstock. This technique is also technically involved as well as requiring an oxygen-containing gas.

The oxygen-containing gas may be pure oxygen, air or mixtures of pure oxygen and air.

In view of the depletion of oil reserves, the partial oxidation of gaseous fuels to synthesis gas, which is a feedstock for many chemicals, is a subject of growing interest.

5 The partial oxidation of gaseous feedstocks can take place according to various established processes.

These processes include the Shell Gasification Process. A comprehensive survey of this process can be found in the Oil and Gas Journal, September 6, 1971, pp 85-90.

10 The partial oxidation of gaseous fuels is usually carried out at temperatures around 900 to roughly 1600 °C, preferably 1100 to 1500 °C and pressures up to 100 bar, preferably 5 to 100 bar.

15 As a consequence of the high partial oxidation temperature and the use of gaseous fuels as feedstocks, the resulting synthesis gas contains no ash, slag, soot or tar, thereby eliminating the necessity of using expensive purification steps.

Raised pressure, high temperature and a gaseous feed lead to a high degree of conversion and relative to the volume of the gasification chamber, they effect a high specific throughput.

20 In the majority of plants in which synthesis gas converted into products such as ammonia, Oxo compounds, methanol or products from the Fischer-Tropsch synthesis and which operate under pressure, a considerable part of the investment required for the compression can be saved on partial oxidizing gaseous 25 fuels under pressure. Compared to the established gasification processes in which ash-containing fuel is employed or which operate under normal pressure, the pressure partial oxidation of gaseous fuel permits a considerable saving in the manufacturing costs of synthesis gas.

30 The endothermic conversion of gaseous hydrocarbons with steam is described in "Encyclopedia of chemical technology" by Kirk-Othmer (3rd edition, 1980); Volume 21, page 543.

Endothermic thermal or catalytic reaction of gaseous hydrocarbons, in the presence of steam to produce carbon

monoxide and hydrogen is an established reaction which is operated industrially using various processes. Such a process can be carried out in a tubular reactor, the necessary heat of reaction being supplied via heat transport through the walls of the tubes or in a medium of externally heated solid heat exchanger material e.g. fine grained solid which is used in a fluidized bed.

5 The known processes necessitate involved technology and exhibit low thermal efficiency.

10 As mentioned hereinbefore the gaseous mixture comprising H<sub>2</sub> and CO formed in the conversion of normally gaseous hydrocarbon(s) with steam (step b) is separated into a CO-containing stream and an H<sub>2</sub> stream. This separation step (c) can be carried out in every possible way e.g. cryogenically, 15 by means of membranes, adsorption and/or adsorption.

It is preferably carried out by means of a pressure swing adsorption process. Such a process is described in US patent specification No. 3,699,218. The CO-containing stream resulting from separation step (c) mainly consists of CO, CO<sub>2</sub> and CH<sub>4</sub>.  
20 At least part of it is preferably used for burning and at least part of the heat generated in this way is used for the conversion of the normally gaseous hydrocarbons in step (b).

At least part of the substantially pure hydrogen stream separated in step (c) is mixed with the synthesis gas produced 25 in step (a). In this manner the H<sub>2</sub>/CO-ratio of this gas is preferably increased to a value in the range from 1.8 to 2.5. Such a gas is very suitable for the synthesis of hydrocarbons according to the Fischer-Tropsch process, which process is described in the book "The Fischer-Tropsch and Related Syntheses" 30 by H.H. Storch, N. Golicic and R.B. Anderson (1951). Therefore the gas obtained in step (d) is at least in part catalytically converted into a product comprising a hydrocarbon mixture. The invention also relates to a process for the production of a hydrocarbon mixture by the catalytic conversion of the

synthesis gas produced in step (d) of the present synthesis gas generating process.

This catalytic conversion is preferably carried out as described in one or more of the following patent documents: UK 5 patent specifications Nos. 1,548,468 and 2,077,289; UK patent applications Nos. 8,320,715; 8,330,993; 8,330,994 and 8,413,595; and Netherlands patent application No. 8,303,909.

The product comprising a hydrocarbon mixture is preferably separated into a gaseous stream comprising non-converted CO 10 and H<sub>2</sub> and low-boiling hydrocarbons, and at least one stream comprising normally liquid hydrocarbons. This separation can be carried out in any possible manner. Advantageously fractional distillation is used for this purpose.

The low-boiling hydrocarbons present in the gaseous 15 stream also comprising CO and H<sub>2</sub>, suitably consist of C<sub>1</sub>-C<sub>4</sub>-hydrocarbons, but higher boiling hydrocarbons may be present in this stream too. At least part of the gaseous stream comprising CO and H<sub>2</sub> and low-boiling hydrocarbons is preferably burned, suitably in a furnace, and at least part the heat 20 generated by this burning is used for the endothermic conversion of at least part of the normally gaseous hydrocarbons with steam in step (b) of the present synthesis gas generating process.

According to another preferred embodiment of the present 25 invention at least part of the gaseous stream comprising CO and H<sub>2</sub> and low-boiling hydrocarbons is used as at least a part of the feed to step (b) in order to be converted with steam into the gaseous mixture comprising H<sub>2</sub> and CO.

According to still another embodiment of the invention at 30 least part of the gaseous stream comprising CO and H<sub>2</sub> and low-boiling hydrocarbons is recycled to step (a) to be partially oxidized to synthesis gas.

As mentioned hereinbefore at least one stream comprising normally liquid hydrocarbons is preferably separated from the 35 product comprising a hydrocarbon mixture.

Preferably at least part of this (these) normally liquid hydrocarbons-containing stream(s) is (are) catalytically hydrocracked, advantageously using at least part of the H<sub>2</sub> stream separated in step (c) of the present process.

5 This hydrocracking step can be carried out in any possible way known in the art. Preference is given to a hydrocracking process using a supported noble metal catalyst as described in European patent application No. 84,201,256.9.

10 The product of the hydrocracking step is preferably subjected to a fractional distillation, at least one normally gaseous fraction comprising non-converted hydrogen and low-boiling hydrocarbons, at least one naphtha fraction, at least one kerosene fraction and at least one gas oil fraction being separated from the hydrocracking product. The naphtha, 15 kerosene and gasoil fractions are withdrawn from the present process as final products.

20 The normally gaseous fraction(s) comprising non-converted hydrogen and low-boiling hydrocarbons (suitably C<sub>1</sub>-C<sub>4</sub>) is (are) preferably recycled as a feed to step (a) and/or step (b) of the present process and/or is (are) advantageously burned for generating heat which is at least in part used in step (b) of the present synthesis gas production process.

25 The synthesis gas with increased H<sub>2</sub>/CO-ratio which is produced in step (d) of the present synthesis gas production process can not only be used for the production of hydrocarbons but also as a feedstock for methanol production.

Therefore at least part of the gas obtained in step (d) is advantageously converted into a product comprising methanol.

30 Suitably a gaseous stream comprising non-converted CO and H<sub>2</sub> is separated from this product and at least part thereof is burned for generating heat which is at least in part used for the conversion of at least part of the gaseous hydrocarbons with steam in step (b) of the present synthesis gas production process.

Substantially pure methanol is separated from the product of the methanol synthesis step and withdrawn as the final product of this step, while heavier products than methanol being obtained in this separation step are advantageously 5 recycled to steps (a) or (b) of the present process to be used as feedstock for these steps and/or as a means for generating heat for step (b).

The present process will now be further elucidated by means of Figure 1 of the drawing, which represents a simplified 10 flow scheme of this process, to which flow scheme the invention is by no means restricted.

Natural gas is introduced via a line 1 into a desulphurization unit 2 where sulphur compounds ( $H_2S$ ) are removed therefrom. The desulphurized natural gas stream is passed via 15 a line 3 into a gasification unit 4 where it is converted by partial oxidation into synthesis gas, mainly consisting of CO and  $H_2$ . To this end air is introduced via a line 5 into an air separation unit 6 where it is separated into a  $N_2$ -containing stream, withdrawn via a line 7 and a substantially pure oxygen stream passed via a line 8 to a line 9 where it is mixed with steam introduced into the system via a line 10.

The oxygen/steam mixture is passed via the line 9 into the gasification unit 4 where it is reacted with the desulphurized natural gas. The resulting synthesis gas having an 25  $H_2/CO$ -ratio below 1.7 is withdrawn from the gasifier 4 via a line 11. It is mixed with substantially pure hydrogen introduced via a line 12 and the mixture having an  $H_2/CO$ -ratio in the range from 1.8 to 2.5 is passed via a line 13 to a hydrocarbon synthesis unit 14 where it is at least in part 30 converted to hydrocarbons. Non-converted  $H_2$  and CO-containing gas mixture together with low boiling hydrocarbons ( $C_1-C_4$ ) is withdrawn from the unit 14 via a line 15. Part of this gas mixture is introduced via a line 16 into a steam reforming unit 17 where it is converted with steam (not shown) into an 35  $H_2$  and CO-containing gas mixture having a higher  $H_2/CO$ -ratio

than the synthesis gas produced in the gasifier 4. Part of the  
gas mixture withdrawn from the unit 14 via the line 15 is  
mixed with a CO-containing stream introduced via a line 18  
into a line 19 and the mixture is passed via the line 19 to  
5 the burners (not shown) of the steam reforming unit 17 where  
the mixture is burned in order to furnish the heat for the  
endothermic steam reforming reactions.

The synthesis gas produced in unit 17 is passed to a  
pressure swing adsorber 20 in which it is separated into a  
10 CO-containing stream withdrawn via the line 18 and a H<sub>2</sub>-stream  
withdrawn via a line 21. Part of the H<sub>2</sub>-stream is passed via  
the line 12 to the line 13. An other part of the H<sub>2</sub>-stream is  
passed via a line 22 to a hydrocracking unit 23 where it is  
used for hydrocracking normally liquid hydrocarbons produced  
15 in the synthesis unit 14 and passed from unit 14 to unit 23  
through a line 24.

The hydrocracking product is passed from the hydrocracking  
unit 23 via a line 25 to a fractional distillation unit 26  
where it is separated into a normally gaseous stream  
20 containing non-converted H<sub>2</sub> and light hydrocarbons, a naphtha  
stream, a kerosene stream and a gasoil stream, which streams  
are withdrawn from the system via lines 27, 28, 29 and 30  
respectively.

C L A I M S

1. Process for the production of synthesis gas with an increased H<sub>2</sub>/CO-ratio from normally gaseous hydrocarbons comprising the following steps:
  - a) at least one normally gaseous hydrocarbon is converted into a synthesis gas comprising H<sub>2</sub> and CO by partial oxidation with an oxygen-containing gas;
  - b) at least one normally gaseous hydrocarbon is converted with steam into a gaseous mixture comprising H<sub>2</sub> and CO;
  - c) the gaseous mixture comprising H<sub>2</sub> and CO, formed in step (b) is separated into a CO-containing stream and a H<sub>2</sub> stream;
  - d) the H<sub>2</sub>/CO-ratio of the synthesis gas produced in step (a) is increased by adding at least part of the H<sub>2</sub> stream obtained in step (c) thereto.
- 15 2. A process as claimed in claim 1, in which at least part of the CO-containing stream separated in step (c) is burned and at least part of the heat generated by this burning is used for the conversion of the normally gaseous hydrocarbons with steam in step (b).
- 20 3. A process as claimed in any one of the preceding claims, in which the H<sub>2</sub>/CO-ratio of the synthesis gas is increased in step (d) to a value in the range from 1.8 to 2.5.
4. A process as claimed in any one of the preceding claims, in which the separation of step (c) is carried out by means of a pressure swing adsorption process.
- 25 5. A process as claimed in any one of the preceding claims, in which the synthesis gas with increased H<sub>2</sub>/CO-ratio is at least in part catalytically converted into a product comprising a hydrocarbon mixture.

6. A process as claimed in claim 5 in which the product comprising a hydrocarbon mixture is separated into a gaseous stream comprising non-converted CO and H<sub>2</sub> and low-boiling hydrocarbons, and at least one stream comprising normally liquid hydrocarbons.  
5
7. A process as claimed in claim 6 preceding claims in which at least part of the gaseous stream comprising CO and H<sub>2</sub> and low-boiling hydrocarbons is burned and at least part of the heat generated by this burning is used for the conversion of  
10 at least part of the normally gaseous hydrocarbons with steam in step (b).
8. A process as claimed in claim 6 or 7 in which at least part of the gaseous stream comprising CO and H<sub>2</sub> and low boiling hydrocarbons is recycled as at least part of the feed  
15 to step (b).
9. A process as claimed any one of the claims 5-8, in which at least one stream comprising normally liquid hydrocarbons separated from the product comprising a hydrocarbon mixture is catalytically hydrocracked using at least part of the H<sub>2</sub>  
20 stream separated in step (c).
10. A process as claimed in claim 9, in which the hydro-cracking product is subjected to fractional distillation and at least one normally gaseous fraction, at least one naphtha fraction, at least one kerosene fraction and at least one gas oil fraction are separated from this product.  
25
11. A process as claimed in claim 10 in which the normally gaseous fraction(s) is (are) recycled as a feed to step (a) and/or step (b), and/or is (are) burned for generating heat which is at least in part used in step (b).
- 30 12. A process as claimed in any one of the preceding claims 1-4, in which the synthesis gas with increased H<sub>2</sub>/CO-ratio is at least in part converted into a product comprising methanol.
13. A process as claimed in claim 12 in which the product comprising methanol is separated into a normally liquid

product comprising methanol and a gaseous stream comprising non-converted CO and H<sub>2</sub>.

14. A process as claimed in claim 13 in which at least part of the gaseous stream comprising non-converted CO and H<sub>2</sub> is  
5 burned and at least part of the heat generated by this burning is used for the conversion of at least part of the normally gaseous hydrocarbons with steam in step (b).

